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FINAL REPORT

MAX '91 COORDINATION AND STUDIES OF SOLAR ACTIVITY ON TIMESCALES OF MILLISECONDS TO YEARS

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INTRODUCTION

Max '91 is a program to study solar activity during the current solar maximum with emphasis on coordination of observations from existing facilities, as well as from new balloon, rocket and ground-based instrumentation. The program and its coordinator have been funded jointly by NASA and NSF. Originally, the period of 1988–1990 was considered to be a planning or "pre-operations" period for Max '91. However, high levels of solar activity accelerated the schedule and the period became a concentrated planning and operational period.

Since the fall of 1988 Alan Kiplinger has served in the capacity of Max '91 Coordinator. In order to perform this coordination effort, and for purposes of conducting independent research, Alan Kiplinger has received support since 1988 from NASA grant NAGW-1462 entitled, "Max '91 Coordination and Studies of Solar Activity on Timescales of Milliseconds to Years." The grant amount was $152,000 for Fiscal Year 1988–1991. The coordination effort has led to the successful completion of three major worldwide campaigns, supported several rocket flights, and set up a near-real-time solar computer data base at NOAA's Space Environment Laboratory. This support includes distributions of campaign announcements with planning information, as well as campaign summaries which provide plots and lists of solar activity and compilations of observations conducted worldwide.

A vigorous pursuit of independent research by the Max '91 coordinator has been an important part of the proposed work. Not only has it allowed this scientist to pursue various long-term objectives, but it has also proven to be beneficial to Max '91 in the sense that the coordinator has a direct need for various types of information to conduct his own observations. This direct need has stimulated the creation of various types of new data that are now available to other scientists over computer networks.

COORDINATION OF MAX '91

Max '91 is a coordinated, broad-based observational program designed to maximize the scientific return of solar activity studies during the current solar maximum. The objectives, observational facilities and program organization of Max '91 are described in the report "Max '91 Flare Research at the Next Solar Maximum" (NASA, 1988). A stated "key" element to the program's effectiveness is the role of an individual solar physicist to act as the Max '91 coordinator .

While the planning and instrument development period has been accompanied by the construction of many new instruments that will participate in Max '91 campaigns, it also has been an active operational period. The first Max '91 campaign was held in June 1989, the second was conducted in December 1990, and the third "target of opportunity" campaign was held in June 1991.

A vitally important component adding to the success of the Max '91 program has been the strong support of NOAA's Space Environment Laboratory (SEL) in Boulder, Colorado. SEL has provided not only office space, but telephone, postal services, secretarial support, computer hardware and software support, and the invaluable services of solar forecaster David Speich, to name but a few. The coordination effort is conducted at NOAA's Space Environment Laboratory (SEL) which provides real-time solar data that is essential to campaign operations. The coordinator works with SEL to not only plan and conduct campaigns, but to develop a variety of information services which help campaign activities. Some of the activities and developments carried out for the Max '91 program under the grant include:

- The first Max '91 Campaign was announced in a detailed "Campaign Announcement" that was delivered by postal and electronic means. The first Max '91 campaign was successfully conducted and proved the validity of various concepts of global communications systems to distribute daily "Campaign Action Notices ."

- A considerable amount of effort was devoted to setting up efficient and reliable means of communications. Max '91 communications now employ electronic mail (e-mail) distribution systems on SPAN, INTERNET, and other networks; electronic file transfers; electronic mail "answerback"; IUWDS Ursigrams; TELEX; postal services; FAX; and telephone to distribute and receive information. Responses from a questionnaire mailed to more than 1300 scientists world-wide resulted in the initial Max '91 participant list. This list is actively maintained and has now grown to 426 scientists.

- By working with NOAA forecaster David Speich efficient means for operating campaigns have been developed. Campaign operations involve target selection from incoming SELDADS and SELSIS data and direct communications to ground-based observers. Daily observing plans, targets, and scientific goals are identified and communicated (in uncoded, plain-English, messages) through the above listed electronic means. Typically, more than 100 scientists can now be notified in less than one hour.

- A second campaign was conducted in December 1990, and the third "target of opportunity" campaign was held in June 1991. In addition, Max '91 has taken steps to coordinate collaborative observations for several solar rocket flights. The announcement for the fourth campaign has been issued worldwide and this campaign, which highlights the Gamma Ray Observatory, is scheduled for October 1991.

- A detailed "Campaign Summary", which summarized observations of the first campaign, was created and delivered to all Max '91 participants. A combined summary is nearing completion for the second and third campaigns. Campaign summaries provide tabular data on solar flares occurring during campaigns as well as GOES soft X-ray plots and summaries of observations obtained worldwide.

- The first Max '91 scientific workshop to address newly acquired Max '91 Campaign data (and some of the last SMM data) was organized and conducted in June 1990. The four-day workshop was held near Estes Park, Colorado, and was attended by approximately 50 active solar physicists. The proceedings have been published as a NASA publication.

- The concept of "campaign leader" was developed to augment scientific expertise in organizing and running campaigns. Campaign leaders have been identified and are already contributing to future campaigns.

- The Max '91 newsletter, MAXFACTS was created and has a current distribution of more than 400 scientists around the world.

- The Max '91 coordinator has actively supported coordinated observations in conjunction with several solar rocket flights, including the dual launch of of the NRL High Resolution Telescope and Spectrograph with the AS & E X-ray telescope (G. Bruekner and D. Moses P.I.s, Nov. 21, 1990); Normal Incidence X- Ray Telescope (L. Golub, P.I., Feb. 22, 1991); Solar EUV Rocket Telescope and Spectrograph SERTS (R. Thomas, P.I., May 7, 1991); and the Multi-Spectral Solar Telescope Array MSSTA (A. Walker, P.I., May 13, 1991). It also supported the rocket/ground-based solar eclipse effort known as CORONA-91 (L. Golub, P.I., July 11, 1991).

- In 1990 the coordinator travelled to the Netherlands for a COSPAR presentation on coordinated solar observations and to the Soviet Union to visit ground-based facilities at Kislovodsk Station of Pulkova Observatory, the Rataan 600, and the Crimean Astrophysical Observatory. In Moscow and Leningrad meetings were conducted with the scientific teams of the CORONAS I and CORONAS F satellite missions. As a result of this trip use of the SOVAM Teleport based in San Francisco has been initiated and successful e-mail communications have been established with the Regional Warning Center in Moscow and the Crimean Astrophysical Observatory. A second result of the trip is that the 36 Soviet scientists on the Max '91 mailing distribution now represent the largest foreign component of Max '91.

- Alan Kiplinger designed and led the SEL software development for the MV 10000 (SEL's prime computer for data acquisition) to supply solar data to scientists during campaigns. Operation of the software is maintained and monitored by the P.I. outside of of campaigns so as to provide a continuous data stream to the scientific community. Some of the products now available via INTERNET, SPAN and telephone as a result of this grant include: archival quality soft X-ray/optical flare plots; near-real-time X-ray plots; X-ray, optical and radio flare listings; activity forecasts by active region; active region data; real-time three-second GOES data. Routine, daily access to the NOAA VAX Max '91 account has already increased to an annual rate of approximately 100,000 file transfers per year over SPAN alone. INTERNET and direct dial in transfers may add another 100,000 transfers.

- The High-Speed Hα Camera was completed an operated as a one camera system in time for the first Max '91 Campaign and was completed as a two-camera system in time for the second Max '91 Campaign in December of 1990. More than 200 Gbytes of data have been collected which contain several hundred Mbytes of flare information. A considerable amount of specialized IDL software has been written for data analysis and a variety of flare studies are underway.

RESEARCH ACTIVITIES

The research involves various efforts. One endeavor has been to anaylze large numbers of hard X-ray flares with regard to their hard X-ray spectra. An automated spectral fitting routine was developed to analyze data from the Hard X-Ray Burst Spectrometer Data from the Solar Maximum Mission Satellite. Developed with assistance from programmers from the SMM Data Analysis Center, the routine can time-divide flares into periods of significant activity, determine good background subtraction periods, remove noise spikes and carry out a variety of spectral fits on the data. This routine finished its analysis of nearly 9,000 solar flares in late 1990 and the data has become available on optical disk as of the March of 1991. To date we have completed the analysis of approximately 95 of the largest HXRBS events and the resulting paper, (Dulk, Kiplinger and Winglee, 1991) has been tentatively accepted by the *Astrophysical Journal* subject to a few minor corrections.

Another main aspect of research is focused upon new observations of solar flares with the High-Speed H-alpha Camera operated in Boulder, Colorado. Until the launch of SMM in 1980, observations of hard X-ray solar flares had generally revealed time variations with timescales $\sim$ 1 s or slower. An important result obtained from the studies of rapid hard X-ray fluctuations, with the improved time resolution of HXRBS on SMM, is that fluctuations do exist on tens of millisecond timescales. Hundreds of fast X-ray spikes with durations of less than 1 s, and rise and decay times of some tens of milliseconds, have been detected (Kiplinger et al., 1983). The existence of rapid variations in hard X-rays offers the opportunity to correlate variations at differing energies on timescales that are considerably less than one second. Electrons with energies of approximately 30 keV will produce many of the solar X-rays which were seen by the HXRBS instrument on SMM and which are being seen by BATSE on GRO. For typical flare loop dimensions of 1–5 $\times 10^4$ km, electrons of this energy should traverse the loop in 0.1–0.5 s or longer depending upon their pitch angle with respect to the loop's magnetic field. Hence, observations on these timescales (or shorter) are required to resolve electron time-of-flight effects and are of great importance in determining the relative contributions of the various processes described above. However, in the absence of hard X-ray images, the Hα emission line (6563Å) is very sensitive to energy release in flares and can provide spatial information very accurately. Detailed observations in Hα can provide a wealth of diagnostic information on differing physical processes including electron beam injection of electrons and thermal heating effects.

In order to study the temporal relationships between H-alpha emission and hard X-rays on very short timescales, the SMM HXRBS team developed the High-Speed Hα Camera system for obtaining digital images of solar flares. The detectors are solid-state charge-injection device (CID) cameras which feature a high signal-to-noise ratio and which provide 128$\times$128 pixel images at the rate of 10 frames per second (timing accuracy is 1 ms). Each camera utilizes high capacity digital recording systems which record continuously at 1.4 megabaud. The telescope employed is the 46cm cassegrain reflector of Sommers-Bausch Observatory (on the campus of the University of Colorado in Boulder) stopped down by a 15-cm-diameter heat-rejecting entrance filter.

During the first Max '91 campaign in June 1989, the High-Speed Hα Camera made its first observations and returned data on 14 of the 16 days of the campaign. Using a single CID detector, images of flaring regions 3$\times$3 arc min across (with 1.3 arc sec pixels operating 1.1Å blueward of line center) were digitally recorded. This camera system continued to operate successfully as a one-camera system (observing in the blue wing of Hα) in conjunction with SMM's Hard X-Ray Burst Spectrometer during periods of high solar activity from June 1989 until the end of the SMM mission. In all, it captured five million images in 1989. After the loss of SMM, hard X-ray data were no longer available; thus, it was an opportune time to return the system to Goddard Space Flight Center for its planned upgrade to a two-camera system.

The upgrade was completed in the fall of 1990 and the system returned to Colorado in time for the second Max '91 campaign in December of that year. The new system features two cameras which share the same optical path. One camera obtains images at Hα line center, while the other camera observes simultaneously at -1.3Å in the blue wing of Hα. The on-band camera is expected to be more sensitive to weak events while flares observed in the blue wing are expected to (and thus far do) show faster, more impulsive behavior.

The camera has observed on all clear days of all Max '91 campaigns, on days of high solar activity during the last 5 months of SMM operations and with several rocket flights. Thus far, it has recorded approximately 200 Gbytes of data. It now appears that perhaps none of the flares observed with the single camera system in 1989 (i.e., observations with HXRBS on SMM) exhibited dramatic sub-second fluctuations as seen earlier by SMM. Nevertheless, many of the events are impulsive and/or large. Several major flares with high-velocity mass motions also were observed during the last days of SMM observations. Although the study of rapid fluctuations was the primary impetus for the development of the high-speed camera, it has become clear that the high-speed digital images are well suited for numerous research endeavors beyond those described above. The thousands of digital images recorded by the high-speed camera in the course of a few minutes during a typical event greatly add to the statistical significance of the observations, even if rapid fluctuations are not apparent in a given event.

Two examples of unexpected behavior are found in data from flares observed during the first and second Max '91 campaigns. On 30 June 1989 a series of flares were recorded from the campaign target region. Series of light curves seen in two similar flares that day clearly show impulsive optical behavior closely tracking the hard X-ray fluxes, but only from the brightest and smallest kernals. Light curves of patches of light far removed from these kernals show rises within 5 s of hard X-ray flux increases, but the curves exhibit a smooth (i.e. integrating) type of optical response with no impulsive peaks to match those seen in hard X-rays. Calculations of propagation velocities between the brightest impulsive kernal and the distant patches indicate speeds of at least 7,000 km/second. This suggests that high-energy electrons may play a role, but the absence of impulsive behavior indicates it is not the same population responsible for hard X-rays (Kiplinger et al., 1991)

An impulsive flare observed during the second campaign on 11 January 1991 (during the extended Max '91 2nd campaign) also was seen simultaneously by the VLA, the Mees Imaging Spectrograph, and the Owens Valley interferometer. (Unfortunately, the flare occurred during an infrequent 5-minute gap in Ulysses data, so there are no known hard X-ray observations.) The camera shows that the flare had a 4 sec e-folding time on the rise with an 18-sec e-folding time during decay with the off-band camera. The on-band camera response was four times slower. By using image motion correction software developed for the camera, it was possible to isolate the light curves of the five flare kernals seen during the event. The analysis revealed that the responses of two of the kernals (the brightest and a fainter one due west of the main kernal) showed matching impulsive peaks. The other three kernals showed less impulsive and differing characteristics. After this inspection of lightcurves we discovered that the magnetic field of the fainter west kernal was opposite to all others; hence, it and the main kernal appear to comprise the region of primary energy release. The main and west kernals also were the only two kernals to exhibit very broad (probably Stark-broadened) wings in Mees' spectrographic data. Broad wings are likely to indicate electron beam interactions in the lower chromosphere. Therefore, the high-speed data are extremely complementary to other data sets and can be directly inspected at all timescales down to 0.1 s. Cross correlation analyses of impulsive flares offer the possibility to examine timing differences even below 0.1 s.

By summing pixels over a kernal, we have shown that variations of total intensity on the order ~0.15% are measurable at a significant level. Summing images (to effectively degrade the time resolution) can push this level even lower. Hence, the images provide an extremely sensitive means to measure for different temporal characteristics in different parts of the flare. Summing images also allows one to improve signal to noise ratios for off-limb studies such observations of coronal mass ejections.

The camera will continue to operate during future Max '91 campaigns and times of enhanced solar activity. The objectives of the research have greatly expanded to study effects other than electron time-of-flight. We are now actively engaged in a study to detect filament formation as we are planning to study linear polarization in flares with a time resolution of 0.4 s.

RESULTING PUBLICATIONS

"Characteristics of Hard X-Ray Spectra of Impulsive Solar Flares." Dulk, G. A., Kiplinger, A. L., and Winglee, R. M. 1991, recommended for publication in *Astrophysical Journal.*

"Contrasting Effects Among Similar Solar Flares Observed on 30 June 1989." Kiplinger, A. L., Orwig, L. E., and Labow, G. J. 1991, in the Proceedings of the third Max '91 Workshop, Estes Park, Colorado, June 1990, p. 210. (An advanced version of the paper is in preparation for submission to *Astrophysical Journal.*

"VLA and Hα Observations of the M8.7 Flare of 17 June 1989: A Preliminary Report." Bastian, T., and Kiplinger, A. L. 1991, in the *Proceedings of the Third Max '91 Workshop*, Estes Park, Colorado, June 1990, p. 153.

"Interrelation of Soft and Hard X-ray Emissions During Solar Flares." Winglee, R., Kiplinger, A., Zarro, Dulk, G. A., Lemen, J., 1991 in press, *Astrophysical Journal*, 375.

"World-Wide Interactive Access to Scientific Databases via Satellite and Terrestrial Data Network." Sanderson, T.R. et al. 1991., *European Space Agency Bulletin*, No. 61., p. 63.

"Access to Max '91 Information via Computer Networks." Kiplinger, A. L.1991, in the *Proceedings of the Max '91 Workshop #2*, Laurel, MD., June 1989, p. 60, 1989.

"The U.S. Max '91 Program of Flare Research." Kiplinger, A. L., and Dennis, B. R., to be published in *Advances in Space Research.*

"H-Alpha Spectra of Dynamic Chromospheric Processes in Five Well- Observed X-ray Flares." Canfield, R. C., Kiplinger, A. L., Penn, M., and and Wulser, J-P. 1990, *Astrophysical Journal*, 363, 318.

"X-Ray Observations of Two Short But Intense Flares." Nitta, N., Dennis, B. R., and Kiplinger, A. L. 1990, *Astrophysical Journal*, 353, 313.

"A High-Speed Digital Camera System for the Observation of Rapid H-Alpha Fluctuations in Solar Flares." Kiplinger, A. L., Dennis, B. R., and Orwig, L. E. 1989, in the *Proceedings of the Max '91 Workshop #2*, Laurel, MD., June 1989, p. 346.

"The Spatial, Spectral and Temporal Character of the Hard X-Ray Flare of February 3, 1982." Nitta, N., Kiplinger, A. L., and Kai, K. 1989, *Astrophysical Journal*, 337, 1003.